Ground Vehicle Condition Based Maintenance

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Agenda

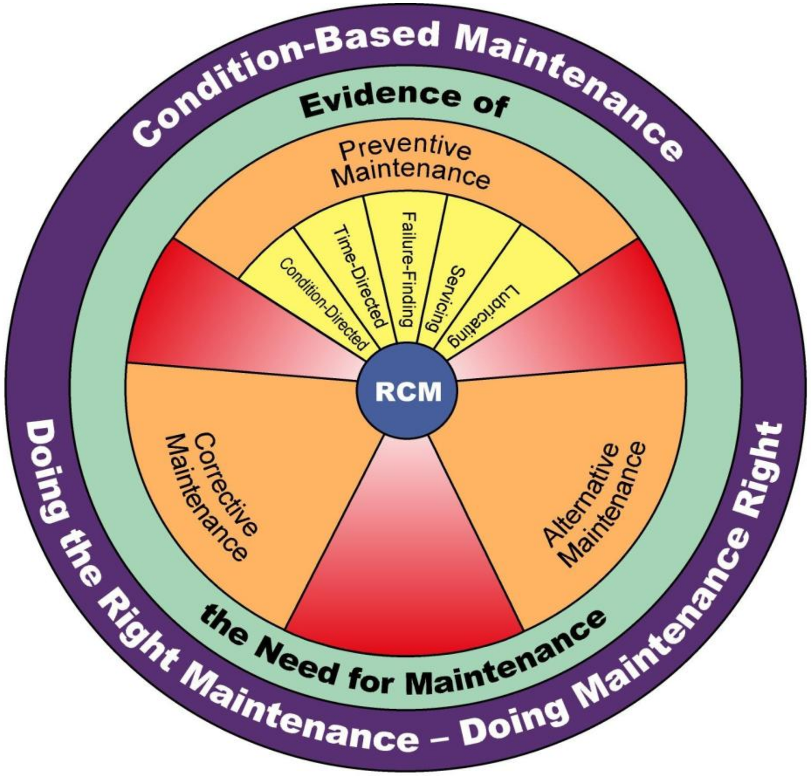
- Ground Vehicle CBM+ Overview
- Logistics Modeling & Simulation
- TACOM LCMC CBM+ Initiatives
- PEO / PM CBM+ Initiatives
  - PM-HBCT Vehicle Health Management System
  - PM-TV CBM Activities
  - USMC PM-AL Embedded Platform Logistics System
- S&T Initiatives
  - TARDEC P&D Process Map
    - Component Testing
  - ARL CBM Research
  - AMSAA SDC & Terrain Modeling

CBM+ Overview

RCM / CBM+ Policy Guidance

- *Army Regulation 750-1, 20 Sep 2007, p. 79* - **Reliability Centered Maintenance (RCM) is the process that the Combat and Materiel Developers use to determine the most effective approach to maintenance. RCM involves identifying actions that, when taken, will reduce the probability of failure and which are the most cost effective. It seeks the optimal mix of condition-based actions, interval (time- or cycle-) based actions, failure finding, or run-to-failure approach.**

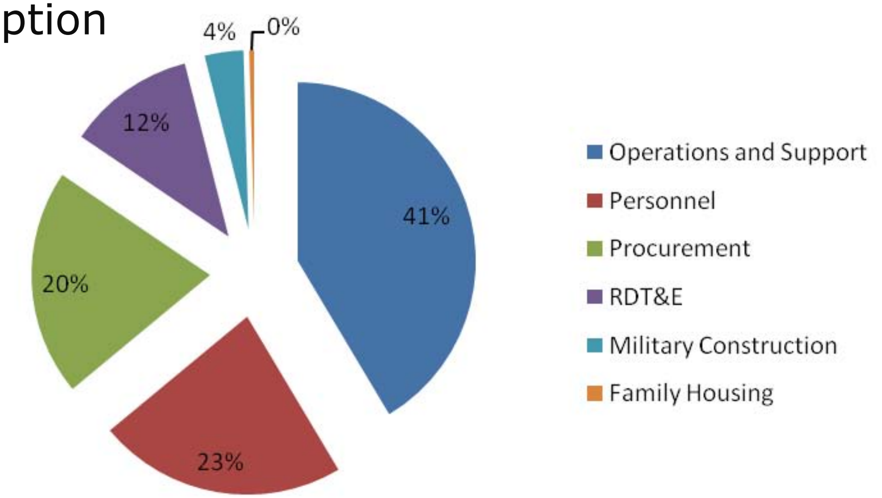
- *DoDI 4151-22, 2 December 2007,* p. 1 - **CBM+ is the application and integration of appropriate processes, technologies, and knowledge based capabilities to improve the reliability and maintenance effectiveness of DoD systems and components. At its core, CBM+ is maintenance performed on evidence of need provided by reliability centered maintenance (RCM) analysis and other enabling processes and techniques.**



RCM and CBM are core processes for CBM+ System Development

Business Challenges

- Why is CBM+ Important?
  - O&S Costs Dominate DoD Spending
  - Need to Reduce Logistics Footprint
  - “Buying” Readiness is not an option



FY2010 US DoD Budget Including Iraq & Afghanistan

- Incentivizing OEMs
  - Current process serves as a disincentive
  - Resistance to Open Standards and Third Party Technology
  - Need to make this “Profitable” for the OEMs

Building Predictive Maintenance

Desired Endstate

Off-Platform Test Equipment

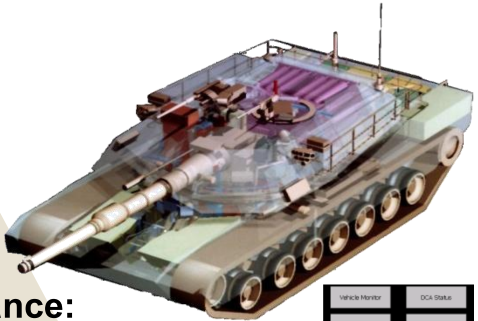
Paper Logbook

Today's Health Management

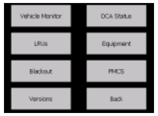
At-Platform Diagnostic Troubleshooting

Maintenance Support Device

Scan Tools



Prognostics:
Predictive Maintenance



Conditional Based Maintenance:
Fact Based,
Trend Analysis

Health Management:
Embedded Diagnostics, Self Reporting, Self Monitoring

Platform Information:
Digital Brigade Combat Team, Electronic Technical Manuals, Built In Test / Fault Isolation Test, Vehicle Diagnostic Management System

Digital Platforms:
Digital Architecture, Data Collectors

Commonality Opportunities - Technologies, Products, & Components

Enablers for Increased Maintainability

Platform Enablers

- Self-reporting Assets & Components
- Fleet Management
- Supply Parts Ordering
- Maintenance Scheduling
- Digital Log Book
- Interactive Electronic TMs

Off-Platform Enablers

- Network Infrastructure
- Data Mining & Analysis Tools
- Fleet Trending and Pattern Recognition – Actionable Data
- Data Synchronization
- Logistics System Integration

Maintainability

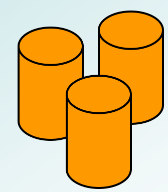
Onboard & At-Platform Prognostics/Diagnostics

- Sensors w/ Sensor Integration HW
- Vehicle Integrated Diagnostic Software (VIDS) w/ Algorithm Manager
- Vehicle Computer System

Army Integrated Logistics Architecture (AILA)

- Enables Net-Centricity
- Defined using DoD Architectural Framework (DoDAF)
- Facilitates Interoperability

Data Standards



- Common Data Format (CDF)
- Open Data Standards
- Data Exchange Standards
- Defined Technical Views

Logistics M&S

FY 2010 NDAA Language

Aberdeen Insights — Predictive Modelling and the Department of Defense and Beyond

This need for better predictive modeling is also being stated by the US government so as to improve the lifecycle management and boost the MRO of assets controlled by the United States Department of Defense. Notes from the Committee of Armed Services in the National Defense Authorization Act for Fiscal Year 2010, indicate that the committee "is concerned about spare parts inventory and supply management by the (armed) services." Notes also indicate that the Government Accountability Office has recommended that spare parts inventory and supply management should be strengthened by improving demand forecasting procedures and by monitoring the effectiveness of providing operational information to item managers. The Committee of Armed Services also encourages the DoD to adopt advanced predictive modeling and simulation methodology that incorporates the asset demand influencing factors to include time, usage, aging of parts, origin of critical parts, maintenance, and logistics support for all aviation and ground equipment programs. In addition, the committee also encourages the DoD to establish pilot programs to demonstrate the benefits of demand forecasting models to reflect cost savings, reduced reliance on unscheduled maintenance, and increased efficiency in supply chain management and budget projections.

Source: National Defense Authorization Act for Fiscal Year 2010, Report on Armed Services, House of Representatives

Making the Case for Implementation of Simulation

•The following complex equation defines A_0 over a Non Linear- Time-Line

$$A(T)=\sum_{k=0}^{\infty}\int_{0}^{T}\int_{t_1}^{T}\cdots\int_{t_{2k-2}}^{T} f(t_1)(g(t_2-t_1))(f(t_3-t_2))(g(t_4-t_3))\cdots f(t_{2k-1}-t_{2k-2})(g(t_{2k}-t_{2k-1}))[1-F(T-t_{2k})]dt_1dt_2\cdots dt_{2k-1}dt_{2k}$$

• Often Assumptions are made that discount "Time" in system behavior

#1 ***f(t) ~ Exp(l) i.e. failures are memoryless (no aging)***

#2 g(t) ~ Exp(m) i.e. repairs are memoryless (no changes to maintenance)

#3 Transient state is negligible (environment is constant)

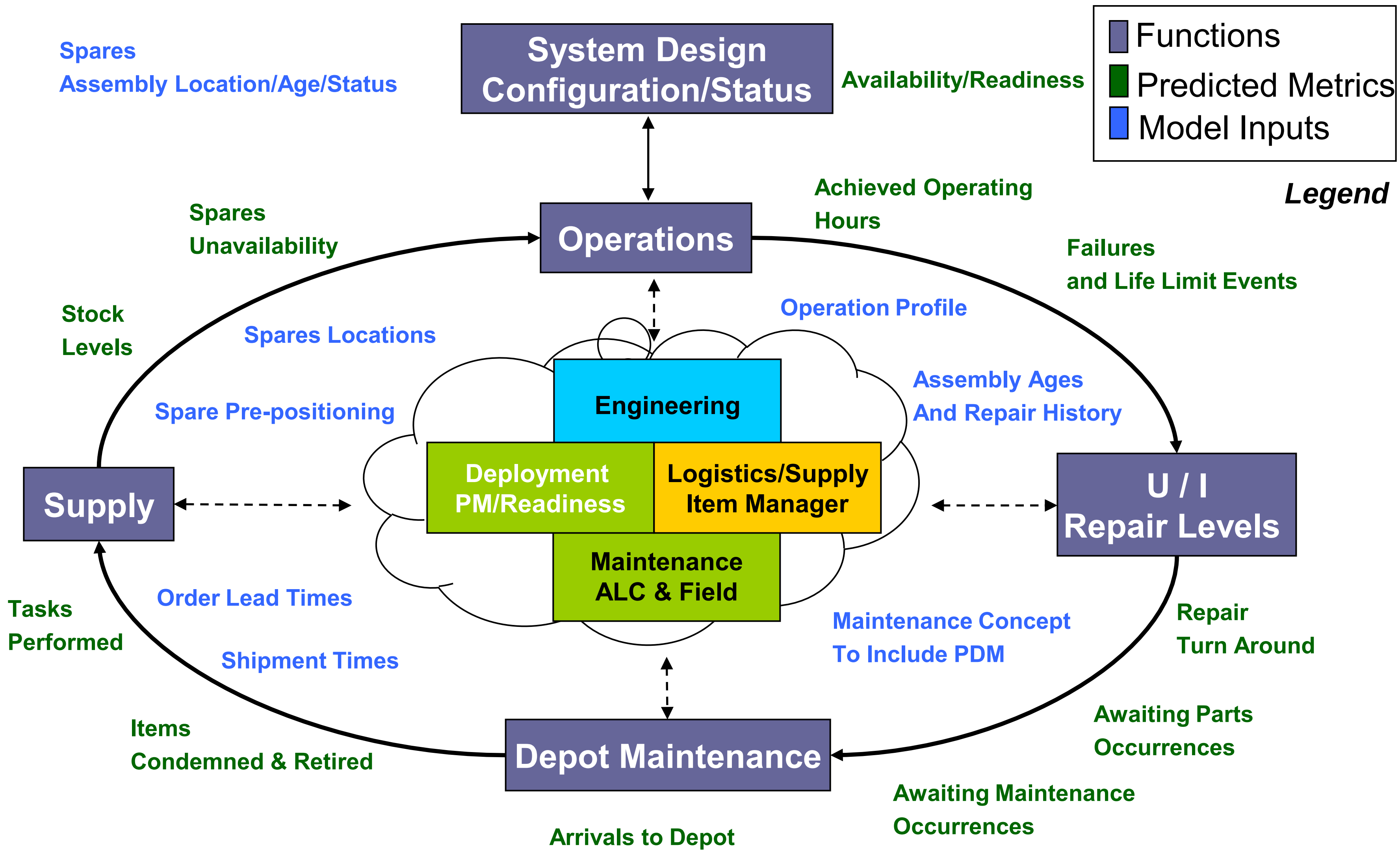
If these assumptions hold…….Then this intractable equation reduces to:

:

$$A(T)=\frac{\mathrm{MTTF}}{\mathrm{MTTR}+\mathrm{MTTF}}$$

Is this simplification really representative of the system behavior, or is this simplification just mathematically convenient?

A Closed-Loop Non-Linear Problem & Many VARIABLES



What Questions Can Be Answered?

VARIABILITY

Reliability **CBM+** **Operations**

- What Spares Must I Take, and What will They Cost, to Support a particular system (Readiness Objectives) ?
- What Workload will be Created Due to the Surge in Operations?
- What Special Repair Capability Must I Take to Support Deployments?
- What Maintenance Strategies Should I Use to Minimize System Downtime and Repair Costs, While Maximizing MTBF (Up-Time/ TOW)?

- What will my Aging fleet cost me next year and beyond if I want to maintain my readiness targets/goals?
- When will there be a financial and/or readiness return on investment in my proposed upgrade/ modification program?
- What will be the resulting workload, and when and where will it occur? Retirement? Mod?
- Where can I refine my strategy in order to improve both the Readiness and Financial Returns on Investment?

Life Cycle Forecasting Options

Logistics Wargaming: Evaluate "What-If" Impacts Due to:

- New or Revised Op-Tempo Programs
  - Business Rules, Processes and Procedures e.g. Business-Surges
  - Terminal or Depot Outage or Transition
  - Network or Infrastructure Expansion, down-sizing/ right-sizing
  - Just-in-Time Inventory Assessments & Planning
- Life-limits and Engineering Change Proposals
  - Part Purging
  - Part Substitutability
- Recapitalization Program Implementation
  - Maintenance Concept Adjustments
  - Repair Effectiveness
- Spares and Part Availability
  - Buy Plan and Initial Provisioning Assessment
  - Obsolescence due to Diminishing Resources
- Budget & Materiel Constraints
- Other Resource Constraints e.g. personnel, training, skills etc.

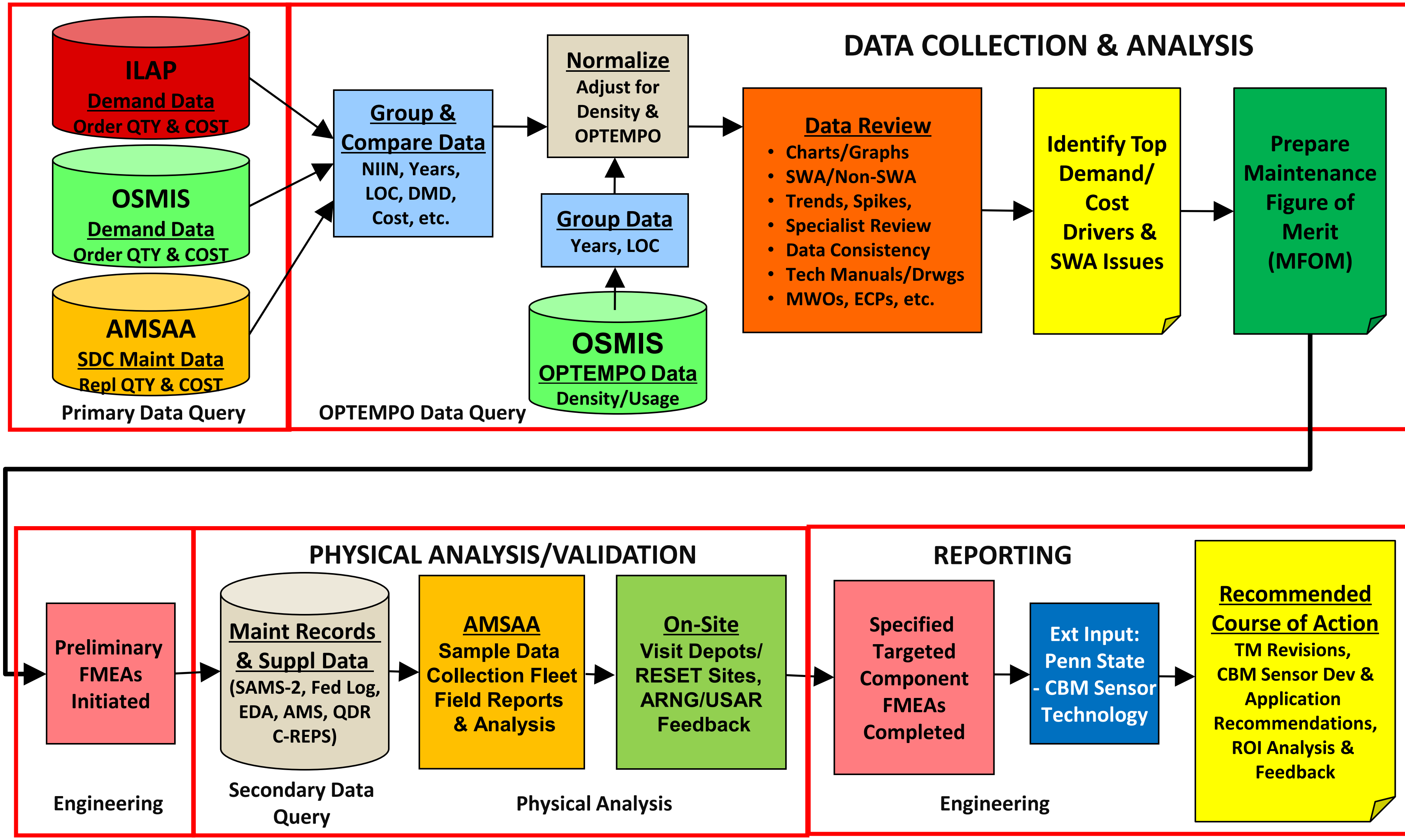
TACOM LCMC CBM+ Initiatives

Condition Based Maintenance (CBM) 4D Data Mining Objective

The objective of this effort was to compile the most significant components with respect to demands over time and based on their importance to the end truck system. Four tactical vehicles were selected by TARDEC for this study.

- Select the particular vehicle components of interest
- Analyze components of the subject truck systems by operational usage data
- Determine maintenance improvements to address high demand/high cost issues
- Compile Failure Modes and Effects Analyses (FMEA)
- Identify usage patterns for application of Condition Based Maintenance (CBM) sensors

4D/CBM Data Analysis, Validation and Reporting Process



FMEA Common Vehicle Components Prevent Cost and Demand Issues

Vehicle Components:

Top 4 on all lists:

1. Engines *
2. Transmissions *
3. Batteries
4. Pneumatic Tires

Top 4 is a similar list for tracked and wheeled vehicles. Tracks replace tires as high cost/demand items for tracked vehicles.

Critical Components:

1. Starter
2. Alternator/Generator
3. Fan Clutch
4. Axles
5. Drive Train/Propeller Shaft
6. Air Compressor
7. Air Dryer
8. Air Brake Chamber
9. Air Brakes
10. Evaporator/Condenser
11. Steering Gear
12. Drag Link
13. Radiator
14. Tie Rod Ends
15. Aligning Rods/Control Arms/Torque Rod
16. …

Root Cause Analysis leads to other vehicle components that deteriorate the Operational Readiness and increase non-mission capable (NMC) vehicle events.

Electronic Maintenance System Next Generation (EMS-NG)

Interactive Electronic Tech Manuals (IETMs)

- **Vehicle diagnostic software link straight to maintenance tasks**
- **Automate data collection tasks to reduce maintenance time**
- **IETM Management to allow updates to be pushed to platforms**

Autonomous Diagnostic Manager (ADM)

Engines

- Caterpillar 3126A, 3126B, C7, C12, C15
- Detroit Diesel DDECII, DDECIII, DDECIV
- John Deere PP45

Transmissions

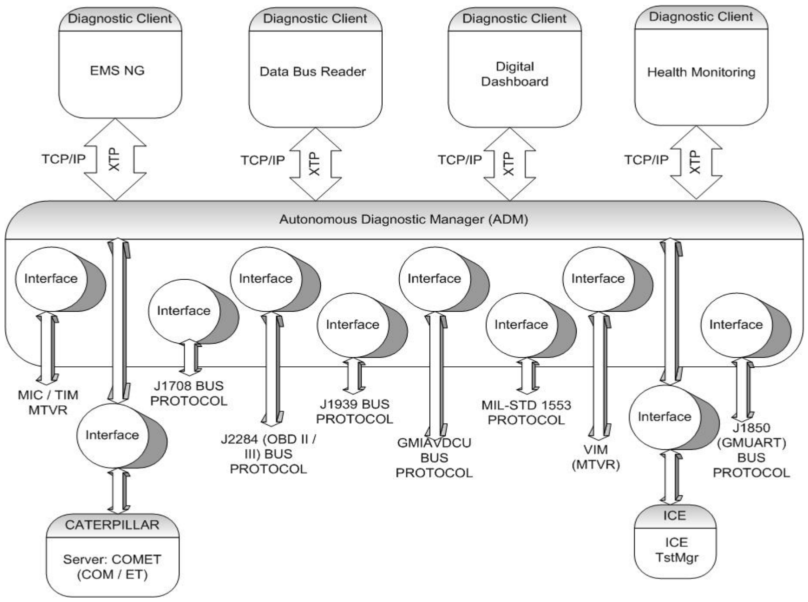
- Allison ATECI, ATECII
- Allison WTEC (Generation 3 and 4)
- General Motors GM4L80E

Antilock Braking System (ABS)

- Eaton, WABCO, HALDEX

Central Tire Inflation System (CTIS)

- Eaton



PM-HBCT VHMS

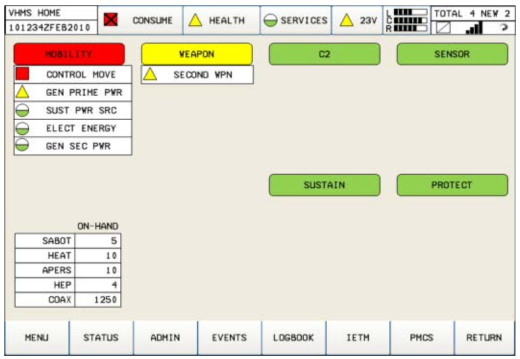
Vehicle Health Management System (VHMS)

Team Members
BAE
CPC
DRS
GDLS
PSU-ARL

- Development of overarching system requirements and architecture for a PM HBCT VHMS implementation
- Enhance and Integrate Diagnostics on platform
- Coordinate off-platform interfaces with Enterprise-level logistics systems (GCSS-A, CBM Data Warehouse)



- Enhance Embedded Diagnostics
- Enable platform data storage and transfer
- Develop & integrate IETMs
- Integrate Ground Digital Log Book (GDLB)
- Plan for future upgrades (LRMs, SRU-level Fault Isolation)



- Centralized Health Management Application
- Common GUI that reduces training footprint for HBCT maintainers

VHMS was formed to solve DSETS/ATE obsolescence issues.

VHMS Key Products

Integrated Solutions

Materiel Solutions

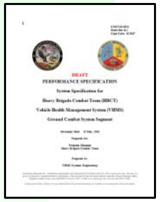
- Ground Digital Logbook
- IETMs
- VHMS Comms Network (VCN)
- E-switch
- Wireless Network Card


EMS-NG(IETM)


Ground Digital LB

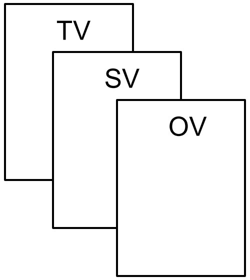

Wireless NIC


E-switch

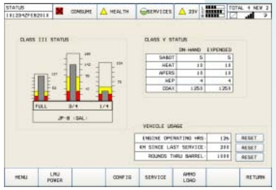

Specifications

Systems Engineering Work Products

- GCS Specification
- Interface Requirements
- User Interface Descriptions
- DoDAF Architecture Artifacts

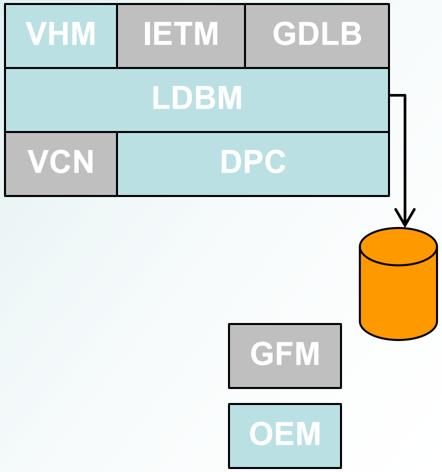


DoDAF Architecture Artifacts


Common Screens

Platform Software

- Vehicle Health Management
- Enhanced Diagnostics
- Logistics Database Management
- Integrating GFM



Technical Challenges

- Software Integration Challenges
  - Common requirements & functionality
  - Different OEM SW development environments
  - Government Furnished SW is developed using different operating systems (i.e. Linux, Windows) and hardware (i.e. laptops, tablet PCs, embedded computers, etc…)
  - Building common data intensive interfaces for System of Systems interoperability
- Prognostic Maturity
  - Lack of success stories drives doubt about prognostic development
  - Lack of historical data makes development difficult and provides little Return-On-Investment justification
- Conflicting PM Priorities
  - While high level guidance regarding CBM Implementation exists, it stops short of a firm platform requirement
  - Even with a firm requirement a platform has traditionally traded RAM technologies for enhanced performance, lethality, and survivability

PM-TV CBM Activities

PM Tactical Vehicles CBM Activities

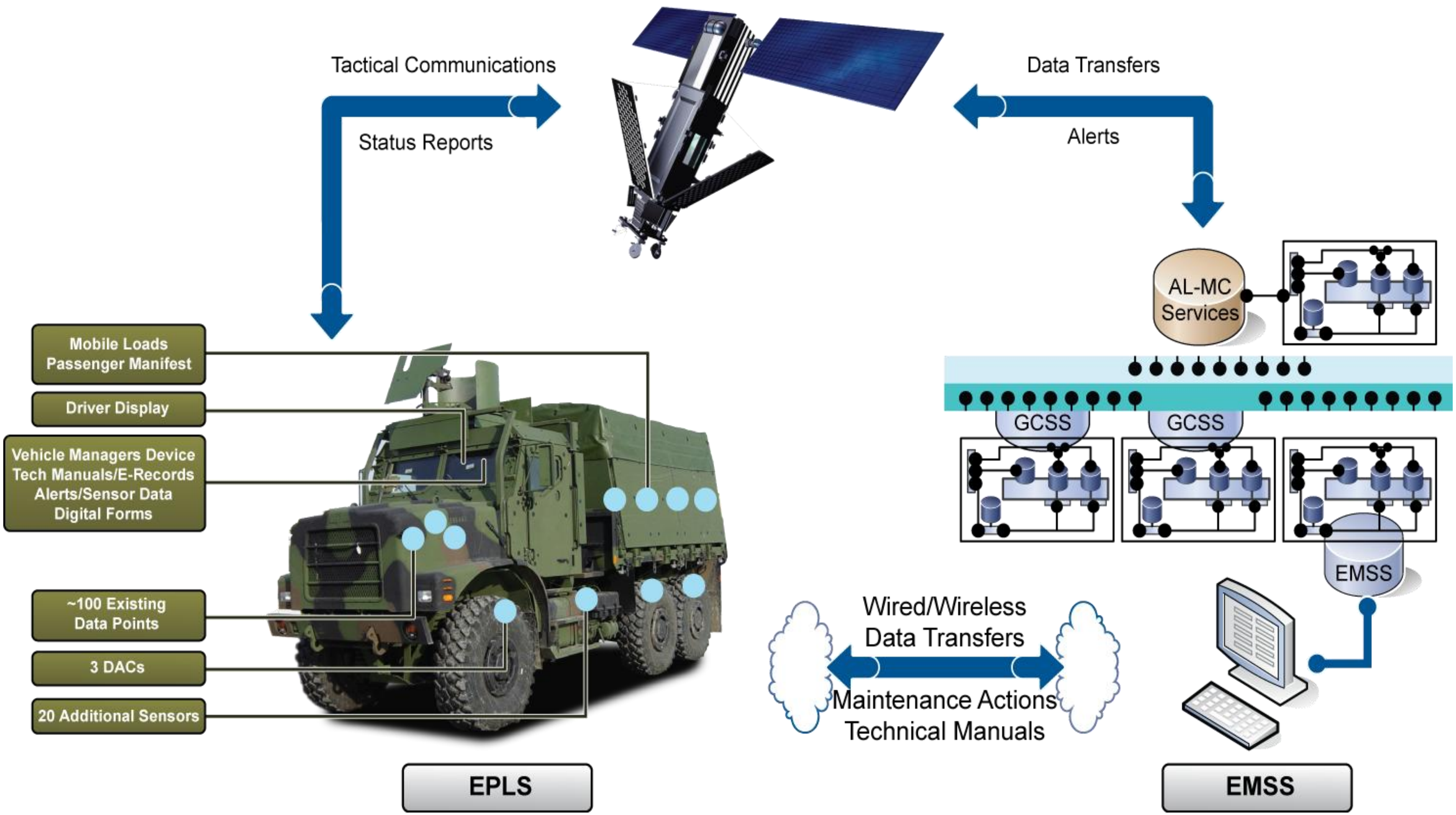
- CBM for TWVs will be built on embedded diagnostics and will concentrate on powertrain and chassis.
- For practicality and affordability, TWVs will utilize low cost, COTS based HW & SW solutions that leverage auto/truck industry standards, practices, and products.
- PM TV needs:
  - Approved requirements and funding for Product Managers to enable CBM “front end”.
  - Logistic and maintenance data analysis to target best ROI opportunities.
  - Continued growth and coverage of embedded diagnostics.
  - Collaborative analysis of fault and failure modes with vehicle/component manufacturers and the scientific and engineering communities.
  - Development of reliable predictive algorithms for a wide range of vehicle components and systems.
  - Establishment of logistic data management networks and applications for collecting and routing CBM information.

PM Tactical Vehicles CBM Activities

- Various electronic modernization activities are occurring during vehicle upgrades, RECAPs, and new production that will support CBM objectives.
  - Automotive and computing industry standard data busses and interfaces
  - Electronically controlled components with embedded sensors
  - Computing, data acquisition, and data storage devices for maintenance and diagnostic purposes
- Coordinating with PD TMDE for development of HW & SW tools to support embedded diagnostics, CBM, and logistic/maintenance data reporting.
  - Wireless Diagnostic Sensor (WDS)
  - Vehicle Integrated Diagnostic Software (VIDS)
  - Standard Army Maintenance Systems-Enhanced (SAMS-E) interface
- Working with TARDEC to develop and mature supporting technologies and processes.
  - Sensors, computing, and vehicle information architectures
  - Logistic and maintenance data analysis
  - Diagnostic and prognostic algorithms
- Coordinating with Logistic Innovation Agency (LIA) and Army/DoD level initiatives.
  - Army Integrated Logistic Architecture (AILA)
  - Common Logistic Operating Environment (CLOE)
  - Proof of Enablers (PoE) exercises and experiments

USMC PM - Autonomic Logistics

Autonomic Logistics Overarching Concept



EPLS Goals

- Provide a basic infrastructure to enable condition based maintenance
- Install an “On-platform” sense capability
- Enable USMC autonomic logistics capability
- Provide stand alone capability that immediately supports the vehicle operator and maintainer
  - Digital, open systems design
  - Networking connectivity
- Platforms – LAV, MTVR, AAV, w/LVSR (Planned)

AL supports achievement of Marine Corps Logistics Modernization goals and objectives

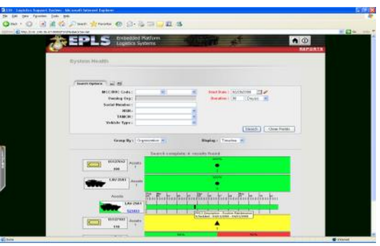
EPLS Vehicle Kit


Data Acquisition/STE-ICE controllers

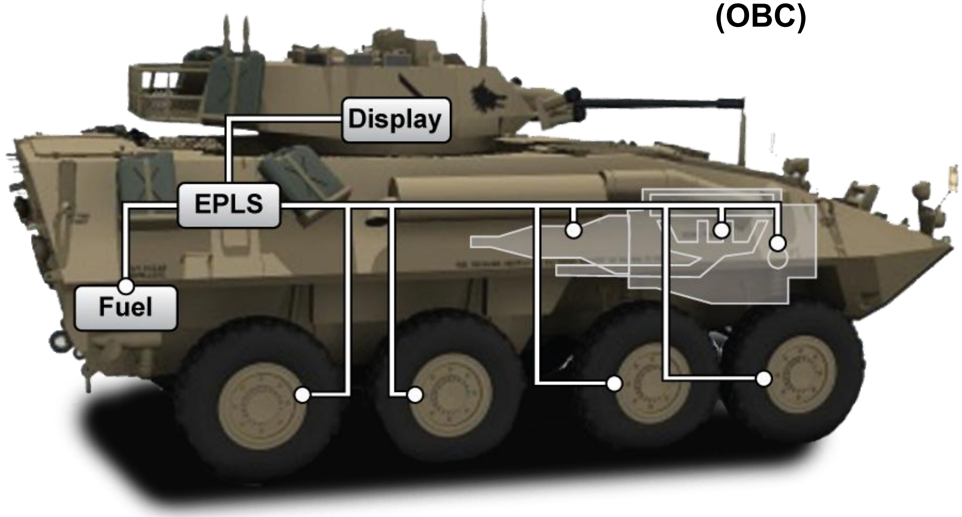
Power Supply

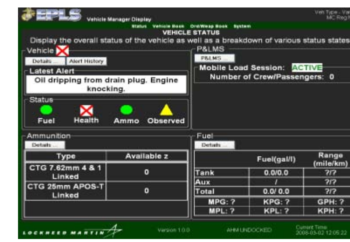
Onboard Computer (OBC)

Driver Position Display (DPD



Off-Board Service Application - Fleet Status Viewer

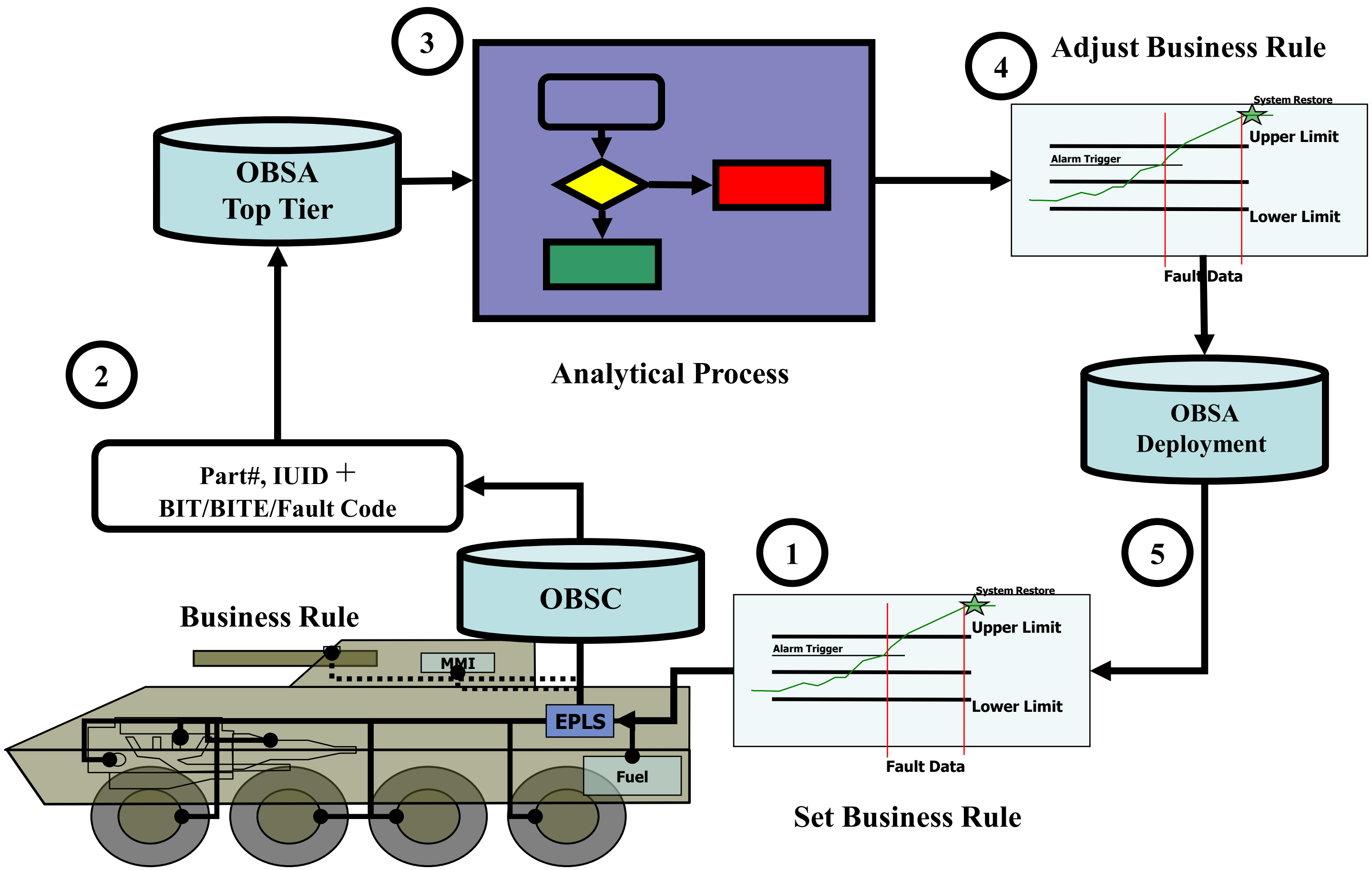




On-Board Software Client

Sensors, Cabling, Digital Data Buss

Condition Monitoring / Assessment



TARDEC S&T Initiatives

Prognostic & Diagnostic Process Map

Focus	Design Factors			Sensor Gaps	Enhance Model	Deploy & Test (Field Sample)
Maint / Cost Drivers	FMEA / FMECA	Physics Of Failure	Design / Perform Experiment	Identify Features	Fit Model & Generate Algorithm	Verify / Validate / Test
Data Mining	SME Expertise		Design & Analysis of Experiments		M&S or Physical Test to Improve Sensitivity	

Analysis :
- ILAP / OSMIS
- AMSAA SDC
- PEO / PM Data

2009/2010 Targets:
- Powertrain
- Track
- Electrical System

Analysis :
- Identify failure modes
- Derive design factors and sensor strategy

FMEAs Developed :
- Diesel Engine
- Transmission
- Alternators

Analysis :
- Identify data features / fault signature
- Data fusion techniques

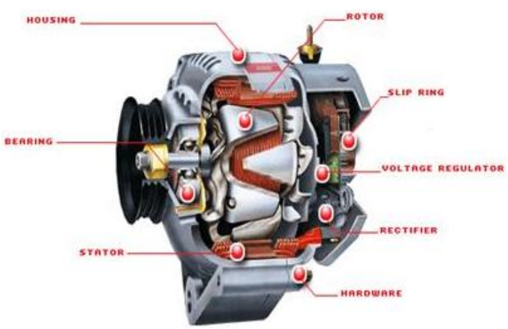
Analytical Tools :
- DOE Tools
- Data Analysis Tools

Algorithm Improvement :
- Model fit to only significant factors and interactions
- Additional tests to improve sensitivity

Testing:
- Team with AMSAA for field testing
- M&S and additional physical testing to introduce more noise factors

Increasing knowledge and capability through proper experimental design and analysis!

Seeded Fault Testing & Algorithm Development



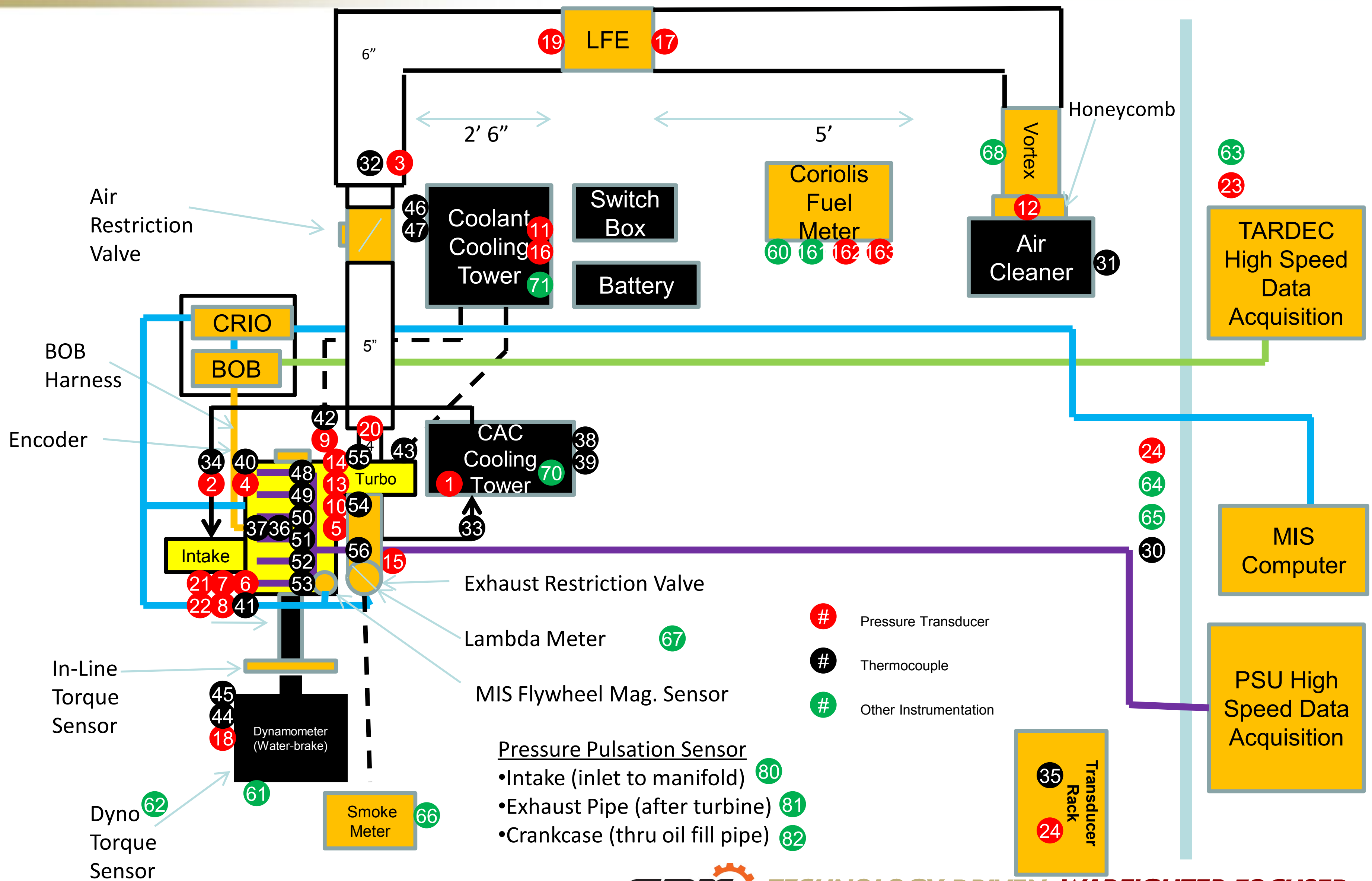
Schedule	FY09	FY10	FY11
CAT C7 Engine			
Allison 2500 Transmission			
Prestolite 130A Alternator			
Li-ion and PbA Batteries			

Purpose:
- Development of health assessment models and algorithms for common automotive components through seeded fault and durability analysis at the component level
- Identification of sensor strategies that could be implemented in a ground vehicle application to allow for accurate diagnosis of impending faults
- Evaluation of the potential Return on Investment (ROI) for implementing these technologies in a vehicle
- Collaboration with AMSAA to evaluate the developed algorithms in a vehicle environment

Products:
- Prognostic and Diagnostic algorithms for selected failure modes
- Sensor strategy for vehicle implementation
- ROI Analysis

Payoffs:
- Provide critical insight into sensors required for diagnosis of component health and prediction of Remaining Useful Life (RUL)
- Allow for replacement of the component prior to a failure that could potentially damage or dead-line a vehicle
- Provide Government owned knowledge that can be applied across a variety of vehicle platforms

Diesel Engine Dynamometer Cell Layout

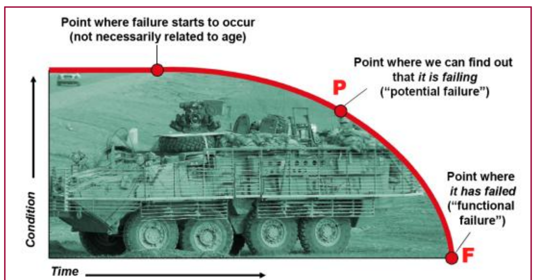


ARL Ground Vehicle CBM S&T Initiatives

ARL Condition-Based Maintenance Research for Ground Vehicle

Objective/Goal:
Develop P&D technologies including physics-based models that accurately predict 40% of vehicle reliability failures

Technical Barriers:
- Inability to accurately & reliably predict vehicle loads and responses
- Inability to predict system failures



Source: Adapted from Moubray, RCM-II.

Milestones (FY)	09	10	11	12	13	14	15
Sensor Study		—					
Physics of Failures		—	—	—	—		
ID Performance Degraders			—				
Analytical Method/Algorithm for RUL	—	—	—	—			
Validation & Tech Integration for CBM					—	—	—

Approach:
- Sensor study to determine baseline of prognostics/diagnostics failure mode coverage
- ID performance degraders of 4 components
- Methodology for determining the remaining useful life (RUL) of high pay-off components

Planned Deliverables:
- Sensor study for P&D failure mode coverage
- Report of performance degraders of 4 high pay-off components
- Analytical method/algorithm for formulating RUL of high pay-off components

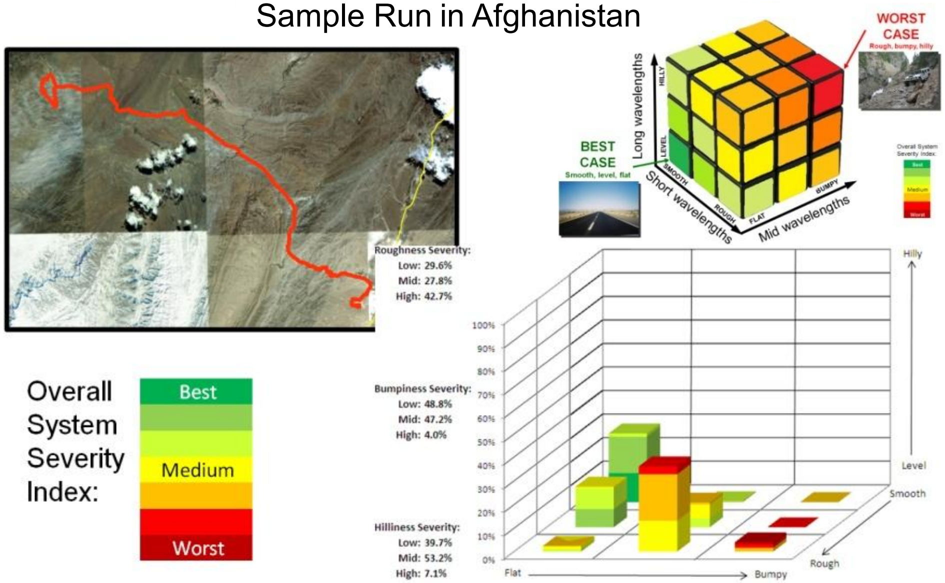
Accomplishments:
- P&D framework for determining RUL developed for generic structural systems

Collaborations:
- VTD (RUL algorithm), SEDD (Sensor Study), WMRD (Physics of Failures, Materials Testing), TARDEC (CBM+ for Ground Vehicles TPA), AMSAA (Data Analysis)

AMSAA - Sample Data Collection

Terrain Regime Identification and Classification

Sample Run in Afghanistan



Payoff: Near Term

- Usage profile classification and reporting.
- Indirect component degradation prediction, and comparative health evaluations.
- Test center to test center, and test center to theatre comparisons.
- Guiding condition based reset.

Payoff: Far Term

- Predict and determine damage accumulation and failures of a vehicle's various sub-systems.
- Integrate into Army's logistic system.

Objectives:

- Develop methodologies and algorithms for the on-board, real-time identification and classification of terrain environments for in-operation wheeled vehicles.
- Relate rates of damage accumulation of a vehicle's various sub-systems directly to the amount of time a vehicle is exposed to the various terrains.
- Predict vehicle health based on damage accumulation algorithms.

Accomplishments:

- Developed methodologies and algorithms for identifying a full-spectrum of terrain regimes.
- Implemented methodology in-theatre on a wide range of operational vehicles.

Technical Approach

- Perform vehicle-specific testing using unsprung accelerometer, GPS, and gyroscope on proving grounds.
- Compute terrain severity thresholds.
- Apply calculated thresholds to data collected in-theatre and compare to vehicle-specific reference data on the same vehicle traversing known terrain types at Army proving grounds.
- Develop predictive algorithms, by relating damage accumulation of a vehicle's various sub-systems directly to the amount of time a vehicle is exposed to the various terrains.